are not sent to the FTF for quality assurance testing.

After being installed at the nuclear facility, an in-place leak test is performed to assure the performance of the confinement ventilation system. Specific objectives of in-place filter testing[1] are (1) to test the aggregate performance of filters in a filter bank, (2) to evaluate the effectiveness of seals between the filter gasket and the filter housing, (3) to assess the leak tightness of the filter plenum, and (4) to determine whether bypasses exist around the filter plenum.

In this chapter each of the components of the performance assurance program are described, with a chapter section devoted to each component. The final section of the chapter discusses needed research in the area of nuclear air cleaning component performance assurance.

8.2 PROOF OF DESIGN - HEPA FILTER QUALIFICATION FOR NUCLEAR SERVICE

Systematic quality control and quality assurance testing are conducted at all stages of the product cycle, from development to use. HEPA filters for nuclear service undergo three qualification routines: (1) a first qualification test performed by a qualified laboratory (the U.S. Army's Edgewood Arsenal) to place the filter on the QPL, (2) a second test at the place of manufacturer, and (3) a third at the place of utilization. In addition, DOE requires a fourth qualification procedure that is unique to that agency.

The former QPL performance testing is now a requirement of ASME AG-1, Section FC.[3] It examines areas such as media penetration, resistance to airflow, resistance to rough handling, resistance to pressure, resistance to heated air, spot flame resistance, environmental conditions, and cyclic exposure. The filter medium receives the most rigorous and extensive control and evaluation.

The manufacturer's qualification procedure involves two distinct phases: (1) a quality assurance/quality control (QA/QC) routine intended to assure careful manufacture of a quality product and (2) a series of tests to verify filter compliance with preset standards concerning the properties of components, the physical characteristics of the assembled filter, and a set of performance criteria related to collection efficiency and resistance to air flow. When all of these factors are within the tolerance limits set by the applicable standards, the manufacturer certifies that each delivered filter unit meets all acceptance criteria.

The qualification that occurs at the using installation is known as the in-place leak test. This test is conducted according to a standard protocol after the installation of clean, new filters to provide assurance that the filter units have been installed correctly in a leak-free filter-holding framework and that the filter units suffered no damage during shipping or installation. The test is essentially a search for defects, not an additional filter efficiency test.

The extra qualification step mandated by DOE involves thorough visual inspection and testing of all purchased filters for compliance with required physical characteristics as well as for efficiency and airflow resistance at the DOE-supported FTF before release to the using agency. Filters failing to meet all applicable criteria are rejected at that point and are returned to the manufacturer for credit. Neither DOE nor the USNRC permit repairs of filters intended for nuclear service. [2]

8.2.1 QUALIFIED PRODUCTS LIST - HEPA FILTERS

As discussed previously, the U. S. Army Edgewood Arsenal developed military standards for HEPA filters and a QPL based on exhaustive tests of the manufacturers' filter media and filters. This facility also performed the QPL testing and began QA testing of HEPA filters. It was mandated that only QPL-listed manufacturers could be used for HEPA filter procurement. The nuclear industry adapted the QPL for its use in procuring HEPA filters. Available American Society for Testing and Materials (ASTM), Technical Association of the Pulp and Paper Industry (TAPPI), and other standard test procedures and equipment were referenced in the documentation of QPL products. Numerous organizations have issued consensus standards incorporating major provisions of the military specification and qualification standards. Those holding the most interest for nuclear service applications are the publications prepared by a standards writing group sponsored by the American Society of Mechanical Engineers (ASME) Committee on Nuclear Air and Gas Treatment (CONAGT), with participation from DOE and the USNRC. Upon the U.S. Department of Defense's (DOD) withdrawal of the MIL standards, the MIL standard requirements were incorporated verbatim into ASME AG-1, Section FC.[3]

Performance criteria for quality products testing include:

- Penetration where the total aerosol penetration through the filter medium, frame, and gasket of a filter that has been encapsulated shall be no greater that 0.03 percent of the upstream concentration at rated airflow and at 20 percent of rated airflow. The reason for the 20 percent flow test is to increase sensitivity for pinhole determination.

- The resistance to airflow at the rated airflow of the filter shall be no greater than 1.0 in.wc for filter sizes 4 and 5, and 1.3 in.wc for filter sizes 1, 2, 3, 6, 7, and 8.[3] See ASME AG-1, Section FC[3] for filter definitions.

8.2.2 EFFICIENCY (PENETRATION)

The performance of a HEPA filter may be expressed either as a collection efficiency (percent of air concentration stopped by the filter) or as a penetration (percent passing through the filter. Concentration may be given by particle count per unit air volume (emphasizing the smallest particles present), particle weight per unit air volume (emphasizing the largest particles present), ionizing radiation intensity per unit volume of air (particle size effect is indeterminate), or light-scattering intensity per unit air volume (emphasizing small particle sizes). Sometimes filter efficiency is expressed as a decontamination factor (DF), the ratio of the untreated air concentration to the treated air concentration (e.g., 99 percent collection efficiency is the same as a DF of 100 and is equal to a penetration of 1.0 percent). The DF descriptor is used most frequently when ionizing radiation is the concentration descriptor.

8.2.3 AIRFLOW RESISTANCE

The resistance of a filter to airflow, often called "pressure drop" and "back pressure," is usually given as the height of a water column that exerts an equal pressure. The characteristic flow regime through HEPA filter media is aerodynamically described as laminar; for this reason, the airflow resistance of these filters changes in direct proportion to changes in air volume even though the air approaching the filter may be turbulent.

The test protocols used to qualify HEPA filters for nuclear service are described below. Bench-testing of all new filters intended for U.S. nuclear service is conducted with a test aerosol in a tester called a Q107 aerosol penetrometer **(FIGURE 8.1)** that was designed by the U.S. Army Chemical

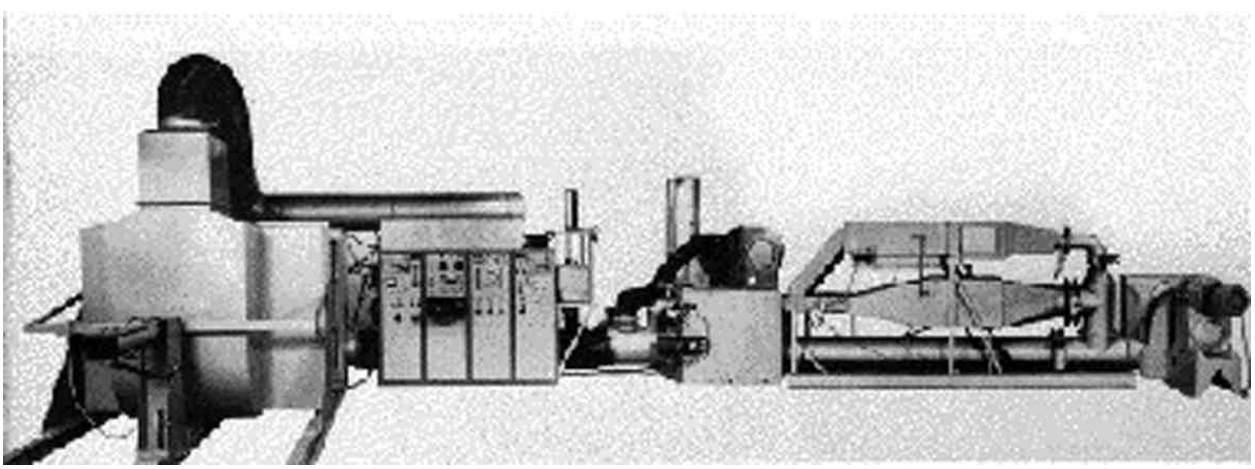

Figure 8.1 – Q107 Penetrometer for efficiency testing of HEPA filters (Equipment contains a thermal DOP generator capable of producing a monodispersed aerosol)
(Photo provided by ATI, Q107 penetrometer)

Corps during the 1950s. Construction and operation of this device are described in DOD MIL-STD-282, Method 102.9.[4] The complete penetrometer consists of a monodisperse test aerosol generator, an instrument that measures the size and uniformity of the particles formed, a clamping device to seal the filter under test into the test fixture, a total scattering photometer to measure test aerosol penetration, and a manometer to measure filter resistance at rated airflow rate.

The size of the test aerosol is determined by passing a sample through an optical particle-sizing instrument called an OWL.[37] and noting the degree of polarization of a light beam. A polarization angle of 29 degrees indicates a particle diameter of 0.3 μm when the aerosol is monodisperse. The brightness and number of red bands produced when the beam is rotated 360 degrees indicates the uniformity of the particles. However, when the aerosol is not precisely monodisperse, the polarization angle read by the OWL represents an average diameter that is not the same as for a precisely monodisperse aerosol.[38] For example, a test aerosol with a count median diameter of 0.232 μm and a geometric standard deviation of 1.15 (perfect uniformity is a geometric standard deviation of 1.0) would give a polarization angle of 29 degrees, whereas a 0.3-μm aerosol with the same degree of size dispersion would give a polarization angle of 45 degrees.[2, 38]

8.2.4 TEST AEROSOL TEST

The basic apparatus and procedure is described in detail in MIL-STD-282.[4] Room air is drawn through filters and split into three streams. One stream of 85 cfm is heated to 365 degrees Fahrenheit and is passed over liquid test aerosol heated to 390 ± 20 degrees Fahrenheit. As the heated air passes over the surface of the hot test aerosol, it becomes saturated with aerosol vapor. When the test-aerosol-saturated air contacts the second air stream (265 cfm held at approximately 71 degrees Fahrenheit, the condensation aerosol is formed. The third stream of diluent air (850 cfm) is introduced in a mixing chamber to dilute and disperse the aerosol-laden air. A forward light-scattering photometer is used to measure test aerosol penetration, and a manometer is used to measure filter resistance at rated airflow rate. Modern penetrometers that use jet impactors to obtain the same aerosol without heating the test aerosol liquid are commercially available.

8.2.5 RESISTANCE TO ROUGH HANDLING QUALIFICATION TEST

The rough handling tester (Q-110) was designed by the U.S. Army Chemical Center (Edgewood Arsenal) to subject a carbon filter to vibration to determine whether carbon channeling would occur during shipping and handling. If channeling occurs, then toxic gases would have a bypass path around the carbon, allowing penetration of the filter. The HEPA filter inherited this test to determine its capability of being transported across country by commercial carriers. It was quickly determined that the carbon filter could not be transported by rail due to an extremely high failure rate. In reality, this test does not actually test the HEPA filter according to the way it is shipped; a commercial vibrating machine designed for this purpose should be used to test the filter. In addition, the filter should be tested in its packaging exactly as it will be shipped, not laid down horizontally and bolted to a table.

In accordance with Method 105.9 of MIL-STD-282,[4] new, unused test filters (at least two of the size and design to be qualified) must undergo rough handling **(FIGURE 8.2)** for 15 min at a total amplitude of 0.75 in. (using sharp cut-off cams that result in both a slow and an instantaneous 0.75-in. drop) and a frequency of 200 Hz, with pleats and filter faces in vertical orientation. The filters must withstand this

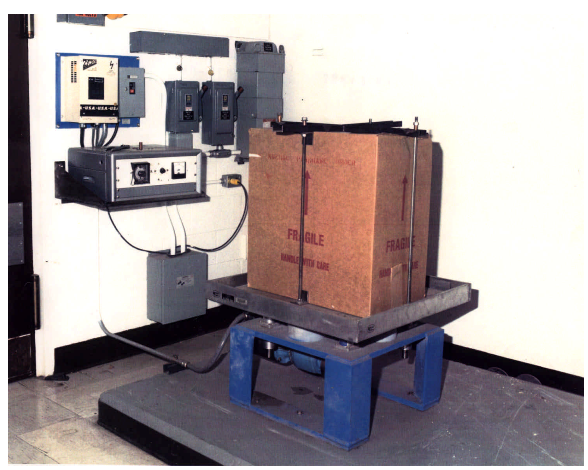

Figure 8.2 – Rough handling machine

treatment without visible damage (cracked or warped frames, loose corners or joints, cracked adhesive, loose or deformed medium) or a decrease in filtration efficiency from 99.97 percent, as determined with nominal 0.3-ìm test aerosol at full and 20 percent flows. DOE randomly performs this test on the filters supplied to it. By indirect reference, this test is a requirement of all U.S. nuclear application specifications.

8.2.6 MOISTURE AND OVERPRESSURE RESISTANCE QUALIFICATION TEST

The overpressurization tester (Q160), which tests HEPA filters at high humidity and at 10 in.wc, also came from a military standard for testing carbon filters that was applied to the HEPA filter. At least four new, unused filters of the type to be qualified must be aged a minimum of 24 hrs under static conditions at 95 ± 5 degrees Fahrenheit and 95 ± 5 percent RH (RH), after which they must be installed in a wind tunnel modified to permit the introduction of water spray **(FIGURE 8.3)**. After conditioning, the filters must withstand a spray of 1.25 lb per 1,000 cfm, adjusted to produce a 10-in.wg pressure drop across the filter, and a flow environment of 95 degrees Fahrenheit. The minimum test duration under these specified conditions is 1 hr. After the test and the filters are dried out, there must be no visible evidence of failure. Within 15 min after completion of the pressure test and while still wet, the 0.3-ìm test aerosol efficiency at full and 20 percent flow must be a minimum of 99.97 percent. By indirect reference, this qualification test is a requirement of all U.S. nuclear application specifications (see ASME AG-1, Section FC, Paragraph FC-5140).[3]

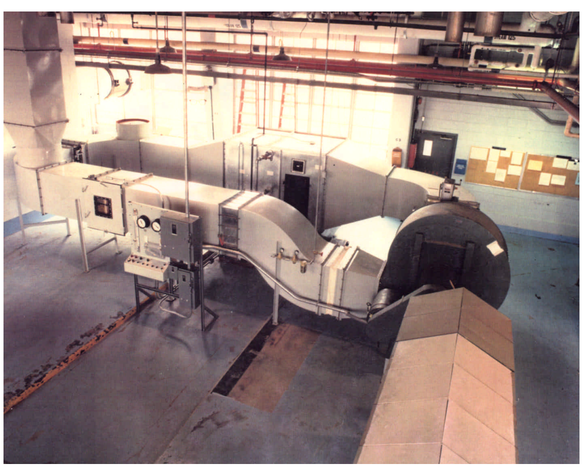

Figure 8.3 - Overpressure Resistance Tester (Q160)

8.2.7 FIRE AND HOT AIR RESISTANCE QUALIFICATION TEST

The high-temperature test, however, came from the nuclear industry as a result of a catastrophic fire at the Rocky Flats site. Related research work also was done at Lawrence Livermore National Laboratory (LLNL). The 700 ± 50 degrees Fahrenheit point of the test was selected because, in laboratory experiments, the HEPA components could withstand temperatures significantly higher. Since industry consensus standards did not come into vogue until the late 1950s and early 1960s, the HEPA filter inherited many then-current military standards and specifications.

New, unused filters must be exposed to heated air in a wind tunnel at 700 ± 50 degrees Fahrenheit for 5 min **(FIGURE 8.4)**. After exposure to heat, the filters must be cooled down and tested in-place, with the filter remaining in the Heated Air unit. An aerosol generator and photometer may be used for the test with an aerosol. The penetration at equal to or greater than 40 percent of rated flow must be less than 3 percent. By indirect reference, this test is a requirement of all U.S. nuclear application specifications (see ASME AG-1, Section FC, Paragraph FC-5150).[3]

8.2.8 SPOT FLAME RESISTANCE

New, unused filters must be tested for spot flame resistance. In this test, the HEPA filter is inverted in a test duct and operated at its rated airflow. A gas flame from a Bunsen burner is directed against the upstream face of the HEPA filter. The Bunsen burner is adjusted to produce a flame with a blue cone 2.5 in. long with a tip temperature of 1750 ± 50 degrees Fahrenheit. The tip of this flame is applied so that it is not less than 2 in. from the filter face. The flame is applied for 5 min at each of three separate locations on the filter face. The Bunsen burner flame then is directed into the top corner of the filter unit such that the tip of the blue flame cone contacts the frame, filter pack, and pack sealant. The flame is applied for a period of 5 min. After the removal of the test flame at each point of application, there must be no sustained flaming (burning) on the

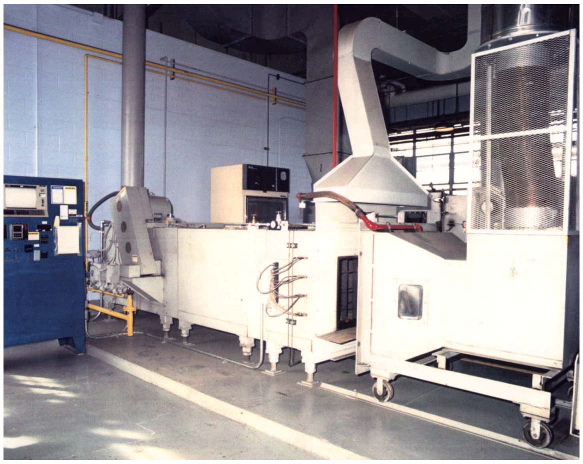

Figure 8.4 – Heated air tester

downstream face of the unit. By indirect reference, this test is a requirement of all U.S. nuclear application specifications (see ASME AG-1, Section FC-5160).[3]

8.3 Quality Assurance Inspection and Testing of HEPA Filters

HEPA filters are critical to the safety of workers and the public in the event of an accident at a nuclear facility. The greatest care is taken to ensure these filters perform both as designed and as assumed in the facility safety analysis. The U.S. Atomic Energy Commission (AEC) identified the need for QA testing of HEPA filters between 1957 and 1958. During this period, the AEC randomly selected filters from stock, and a significant number were found defective. In 1959, the AEC initiated QA testing at the Hanford and Edgewood Arsenal sites. Operations at the Oak Ridge FTF (ORFTF) and Rocky Flats FTF (RFFTF) followed in January 1963 and 1974, respectively. Historically, these FTFs have provided over forty years of progressive QA testing and delivering of a critical quality component. The ORFTF is the last of the three DOE HEPA FTFs remaining. DOE continues to perform 100 percent QA receipt inspection and efficiency-pressure drop testing on certain HEPA ventilation filters produced for use in DOE nuclear facilities. This is to ensure that filtration efficiency meets DOE's specification requirements. Such QA testing ensures that the last barriers of protection against the release of particulate radioactivity to the environment at DOE nuclear facilities are performing as they should. Historically, the rejection rate continues to fluctuate, as shown in **TABLE 8.1** below, with a high of 18.7 percent in 1996 decreasing to 1.6 percent, then increasing to 9.8 percent and 8.1 percent in 2000 and 2001, respectively. Significant reported rejection rates indicate that vendor testing is not sufficient.[5] From this data, it is apparent that an independent test facility is necessary to ferret out any defective filters shipped through the manufacturer's inspection process.

Table 8.1 – Oak Ridge Filter Test Facility Testing Activities – FY 1996 – FY 2001

Fiscal Year	Number Received	Number Accepted	Number Rejected	Resistance	Penetration	Manufacturing Defects	Does not meet PO and/or Spec	Shipping Damage	Rejection Rate
FY1996	2643	2150	493	371	70	35	17	0	18.7%
FY1997	2916	2814	102	59	20	7	16	0	3.5%
FY1998	2305	2237	68	1	28	3	34	2	3.0%
FY1999	2362	2325	37	0	31	6	0	0	1.6%
FY2000	3597	3243	354	0	44	36	270	6	9.9%
FY2001	2713	2494	219	3	39	46	123	8	8.1%
Total	**16536**	**15263**	**1273**	**434**	**232**	**133**	**460**	**16**	**7.7%**